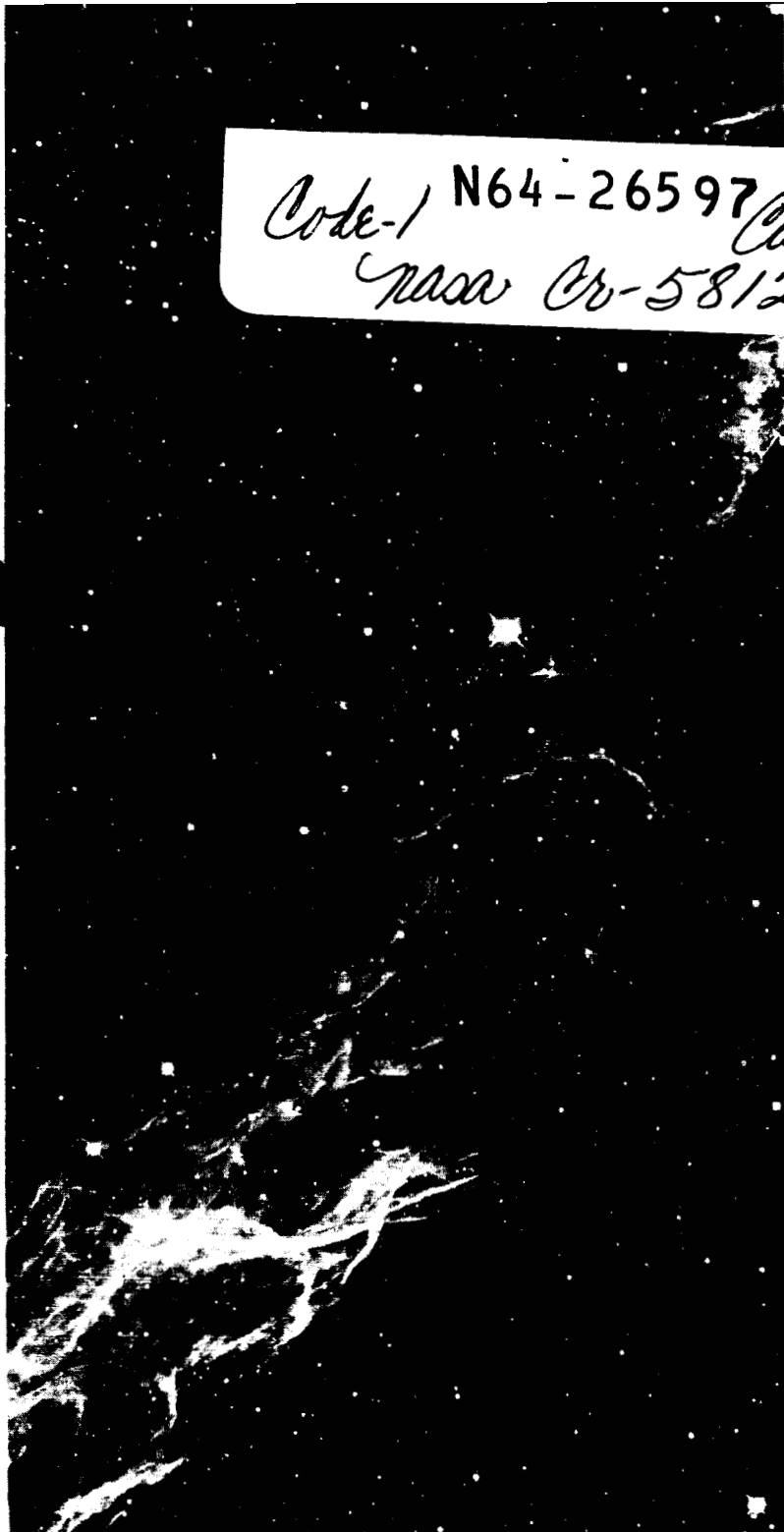


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SUMMARY OF FLIGHT MISSIONS TO JUPITER

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SUMMARY OF FLIGHT MISSIONS TO JUPITER

by

Astro Sciences Center

of


IIT Research Institute
Chicago, Illinois

for

Lunar and Planetary Programs
National Aeronautics and Space Administration
Washington, D. C.

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APPROVED:


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Astro Sciences Center

July 1, 1964

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FOREWORD

This report is a condensation of the ASC/IITRI reports No. M.1. entitled "Survey of a Jovian Mission" and P.1 entitled "The Scientific Objectives of Deep Space Missions - Jupiter". It presents the major findings and conclusions contained in the full reports.

TABLE OF CONTENTS

	<u>Page No.</u>
1. INTRODUCTION	1
2. THE PLANET JUPITER	2
3. SCIENTIFIC OBJECTIVES AND SUGGESTED EXPERIMENTS	3
3.1 Magnetic Fields	4
3.2 Energy Balance	4
3.3 Temperature	5
3.4 Atmospheric Composition and Pressure	6
3.5 Trapped Radiation	6
3.6 Surface and Cloud Features	7
3.7 Altimeter	7
4. SPACECRAFT AND SUBSYSTEM CONSIDERATIONS	7
4.1 Shielding	7
4.2 Data Handling	8
4.3 The Data Link	9
4.4 Power Supplies	9
4.5 Spacecraft Weight	10
5. VEHICLE PERFORMANCE AND VELOCITY REQUIREMENTS	10
5.1 Launch to Earth Orbit	10
5.2 Transfer to Jupiter	11
5.3 Terminal Maneuver	12
6. CONCLUSIONS AND FINAL COMMENTS	13
Tables and Graphs	15

SUMMARY OF FLIGHT MISSIONS TO JUPITER

1. INTRODUCTION

The exploration of Jupiter and its neighborhood represents one of several classes of space mission which are at the limits of current capability. A mission to Jupiter typifies in many respects the deep space mission which will be exposed to difficult but not extreme environmental conditions and operational restraints. This report is a condensation of Astro Sciences Center Report M-1 "Survey of a Jovian Mission" submitted to the Lunar and Planetary Programs Office of the National Aeronautics and Space Administration. It is intended to present only the highlights of that report, and more complete treatment of the subject matter should be obtained from the survey report itself.

The purpose of the study was to explore the feasibility of an unmanned scientific mission to Jupiter to obtain astrophysical information concerning the planet and its environment. The report deals primarily with an overall assessment of the problem areas which must be considered in successfully completing a Jovian mission and attempts to establish the feasibility of achieving such a mission using present state of the art vehicle technology, and scientific payload. The report concludes that

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a useful scientific mission to Jupiter is feasible with presently available chemical propulsion techniques, sensors, power supplies, telemetry links and boosters. The development of a high performance final stage rocket compatible with the vehicles considered was found to be desirable for either a fly-by or orbiter mission.

2. THE PLANET JUPITER

Jupiter, as the largest and most massive planet in the solar system, is of great scientific interest to the geophysicist as well as the astrophysicist. Table 1 contains data on the planet. It lies in an orbit at a mean radius from the Sun of 5.2 AU and exhibits a mean temperature of some 150°K. Its atmosphere is deep and is composed of hydrogen and helium, with some methane and ammonia. Clouds appear to be absent in the polar regions, and optical scattering properties at the polar cap differ widely from those in the equatorial zone. The planet is characterized by a large mass (318 times that of Earth) and a diameter 11 times that of Earth. This provides a gravitational attraction of 2.65 g at the surface which requires an escape velocity of over 5.5 times that on Earth. Its low density, approximately one quarter that of Earth, leads to the supposition that the interior may be solid metallic hydrogen. This, however, is difficult to correlate with the fact that the surface magnetic field of Jupiter appears to be asymmetrical and as much as 1600 times stronger than that of Earth where the dynamo theory of circulating fluid currents has been hypothesized to explain the magnetic field.

Electromagnetic signals emitted from the proximity of Jupiter have been detected by radio telescopes and could be explained by the assumption that trapped radiation is associated with a strong Jovian magnetic field. This radiation belt may provide a hazard to both unmanned and manned vehicles orbiting Jupiter.

It would seem probable that the early missions will orbit the planet at the minimum altitude compatible with atmospheric drag and trapped particle radiation, and will depend upon observations in visible light and electromagnetic sensors to determine surface and atmospheric characteristics. Thus a knowledge of Jovian atmospheric composition and density as a function of altitude and the transmission and scattering characteristics of the atmosphere from radio frequencies through the soft x-ray region is important to succeeding missions in addition to the intrinsic interest.

3. SCIENTIFIC OBJECTIVES AND SUGGESTED EXPERIMENTS

The scientific objectives for a mission to Jupiter have been covered by Report P-1, "Jupiter" in the ASC Scientific Objectives of Deep Space Investigations report series and will be only briefly mentioned here in relation to the proposed scientific payload structure. Table 2 summarizes the scientific objectives and Table 3 summarizes the suggested experiments.

3.1 Magnetic Fields

Measurements of the Jovian magnetic fields are of paramount importance because the existence and magnitude of the fields are fundamental to the understanding of the planet's magnetic history, the origin of radio emission, the ability to retain trapped radiation belts, and models describing the planet's interior. Measurements of the Jovian magnetic field must be made in the vicinity of Jupiter, and require that magnetometers be included in the scientific payload. While the Jovian magnetic field may be in the vicinity of 100 gauss at 3 Jovian radii, it would be well to have a dynamic range from 10^{-5} to 100 gauss so that the interplanetary magnetic field can also be measured. A system combining the rubidium vapor magnetometer and a search coil magnetometer is suggested, in order to cover the extreme dynamic range.

3.2 Energy Balance

The energy balance in the Jovian atmosphere cannot be understood on the basis of the experimental data presently available. Based upon computed incident solar radiation at 5.2 AU and a surface albedo of 0.67, a temperature of 93°K can be calculated. Infrared measurements and radio emission spectra which are believed to be related to thermal emission both indicate a temperature in the region of 150°K. The black body radiation for this temperature has a maximum value at a wavelength of 20μ with a large percentage of the radiation falling between 10μ and 50μ . This does not correlate with

the absorption bands for either methane or ammonia which are believed to form a portion of the Jovian atmosphere. The mechanism for retaining solar energy in the Jovian atmosphere is not resolved, and a look at the atmosphere in the region from 10μ to 50μ is required.

Using a diffraction grating in conjunction with either a Golay cell or solid state detector, a suitable infrared spectrometer for the region of interest can be constructed and would weigh about one pound and would require not more than five watts of power.

3.3 Temperature

Closely allied to the problem of heat balance is the question of temperature distribution, density and composition of the Jovian atmosphere. It is proposed to measure temperature by means of a microwave radiometer in four selected millimeter wavelength bands. In these wavelengths, an average temperature of about 150°K has been obtained for Jupiter which correlates well with the infrared measurements made in 1926. In the longer centimeter wavelengths, other radiation mechanisms than thermal predominate and obscure the thermal component. A suitable millimeter wavelength radiometer can be constructed with a total weight of approximately seven pounds and a power consumption of about one watt.

3.4 Atmospheric Composition and Pressure

Composition, pressure and possibly temperature of the Jovian atmosphere can be obtained with a visible and ultra-violet spectrophotometer-polarimeter system which would operate in the 1000\AA to 5000\AA region with a resolution of 10\AA and sufficient spatial resolution to distinguish limb and terminator effects. To date, methane, ammonia and hydrogen have been identified spectroscopically and helium has been inferred. Spectroscopic examination at close range would permit considerable spatial resolution which is at present unachievable from Earth.

A suitable spectrophotometer system with an intensity accuracy of five percent and a dynamic range of three to four decades could be designed for ten pounds with a power consumption of approximately five watts using solid state photosensitive detectors.

3.5 Trapped Radiation

The existence of trapped radiation belts around Jupiter has been hypothesized from the large magnetic fields that were invoked to explain the radio emission. It has been suggested that two trapped radiation belts exist; one centered at 1.5 Jovian radii and the other at 3.0 Jovian radii. These belts are pictured as being asymmetrical to the planet's axis as the result of an asymmetric dipole moment. The distances quoted are consistent with the fact that radio emission is observed at a distance of three radii from the planet. Suitable

sensors using geiger counters, scintillation detectors or solid state detectors are conventional and could be designed to also measure cosmic ray flux and proton and electron flux in the solar wind by incorporating a wide dynamic range. They could be designed as small as two or three pounds with a consumption of one watt.

3.6 Surface and Cloud Features

The problem of photography of the cloud cover and surface features of Jupiter is largely one of optical resolution balanced against the communication bandwidth available. A television system using around 200 lines could be used to observe either the complete planet or, if sufficiently close, particular areas of interest such as the red spot. The weight of the TV system would be about 20 pounds and the power requirement about 20 watts.

3.7 Altimeter

Some measure of the distance of the spacecraft from the planet is essential in order to make magnetic and radiometric measurements meaningful. This can best be done with a radar altimeter in the X band using a two foot diameter dish. The peak power of such a system would be between 100W and 500W to be effective up to approximately 10 Jovian radii. An average power consumption of only a few watts is necessary, however.

4. SPACECRAFT AND SUBSYSTEM CONSIDERATIONS

4.1 Shielding

A spacecraft traveling more than 4 AU to Jupiter for a period of 300 to 500 days will be exposed to many forms of

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potentially damaging radiation and bombardment. Complete protection of the spacecraft and its payload under all conceivable situations is not feasible because of the huge mass of shielding involved. A realistic assessment of the most probable environmental hazards must be made and protection provided to cover these at a nominal cost in payload capability.

The probability of encounter with one or more meteoroids of mass larger than 10^{-5} gms traveling at velocities between 12 to 80 km/sec is quite high for a mission of this duration. Radiation shielding from solar particles and trapped radiation in the Jovian field is also a prime consideration, as well as shielding from leakage flux from on-board nuclear power sources. The high magnetic fields believed to be associated with the planet create a problem in connection with the electronics of the system and will require magnetic shielding. Report M-1 discusses the design of a combination shield which would be capable of a reasonable amount of protection from meteoroids, charged particles and magnetic fields, with the minimum size and weight penalty.

4.2 Data Handling

Under this heading come the functions of data conditioning, monitoring of engineering data and the timing and generation of appropriate commands to control systems. Also included are the monitoring of homing system outputs, and generation of trajectory correction commands. These functions are common to almost all previous space probes and require no

further elaboration. The possibility of having to employ an on-board trajectory correction capability can be estimated once a detailed study of the trajectory and launch vehicle accuracy have been computed. It is estimated that the total weight of the data handling equipment could be held to approximately 25 pounds with a power consumption of less than five watts.

4.3 The Data Link

The requirements for the data link system in the spacecraft will be determined by the sensitivity and number of ground stations on Earth receiving the signal, the distance to be covered, the quantity of data to be transmitted and the required accuracy of transmission. Approximate bit rates are listed in Table 4. Under the assumption that a full network of receiving stations on Earth will be available, a transmitter power of 100 watts should be capable of sending a usable signal on Earth based upon the transmission of 100 bits per second at 1 mc bandwidth. In general the experimental package demands transmitter powers under 100 watts. However, the use of long storage times for TV information is essential in order to keep the bit rate low. (75 b.p.s., for example, will allow transmission of one frame every 8 hours.) The weight of a 100 watt transmitter would be of the order of ten pounds.

4.4 Power Supplies

Considering all requirements including telemetering, total power demand ranges from 30 kilowatts down to 200 watts for the missions considered. Power requirements of this size would

indicate that present solar cells and energy storage batteries would be impractical at 5 AU or more. The most probable power source would be either a nuclear reactor system or a radioactive isotope device. Nuclear power sources are still in the developmental stage, but it seems probable that a 1 kilowatt source can be developed which weighs in the vicinity of 1000 pounds, i.e., roughly one pound per watt.

4.5 Spacecraft Weight

Three payload configurations (four weights) ranging from a minimal mission with a very simple experimental package to a comprehensive mission with high resolution experiments were considered. Table 5 provides subsystem and total weights. No explicit redundancy of components or subsystem has been included in these estimates. Nor have we projected any large advances in spacecraft or technology instrumentation state of the art in the period before missions to Jupiter are initiated.

5. VEHICLE PERFORMANCE AND VELOCITY REQUIREMENTS

The dynamics of the mission to Jupiter have been considered in three separate parts:

- a) Launch to Earth orbit
- b) Transfer from Earth orbit to Jupiter
- c) Terminal maneuver

5.1 Launch to Earth Orbit

Very rough estimates of the velocity requirements for transfer orbit were coupled with approximate payload weights at an early stage in the study and indicate that worthwhile missions

might be accomplished with next generation chemical rockets if a high performance stage is added. We have considered three basic launch vehicles having boosters with an escape capability of 2000-3000 lbs., 6000-7000 lbs., and 60,000-80,000 lbs. These have been designated Vehicle 1, Vehicle 2, and Vehicle 3, respectively.

When computing the velocity increment that must be imparted to the spacecraft, one must also consider the energy necessary to escape from Earth. The lowest total energy requirements are obtained by considering direct launch from Earth. However, this greatly limits the launch window and as a consequence we have assumed final injection from a parking orbit.

5.2 Transfer to Jupiter

It has been assumed that only one gravitating body (the Sun) is acting and that the duration of any thrusting period is sufficiently short so that the angular motion around the principle gravitating body is negligible. The flight path then reduces to a conic section, and the motion along the path is readily discernible. Conic section trajectories have been generated with the IITRI IBM 7090 computer facility to give a series of curves relating excess spacecraft velocity (over the asymptotic Earth escape) to the launch date. Knowing the vehicle payload and performance, it is possible to obtain launch window duration and

dates from these curves. The curves are plotted for various travel times in Report M-1, "Survey of a Jovian Mission". A summary of this data is given in Figure 1.

The accuracy of the launch vehicles is currently insufficient to achieve a reasonable miss-distance at Jupiter without the addition of midcourse correction capability. The desired accuracy for the distance of closest approach measured from the center of the planet has been specified as 3 Jovian radii \pm 1/2 Jovian radius based upon the requirements of the scientific experiments. It is assumed that the first correction to the spacecraft trajectory would be made in the vicinity of the Earth several days after launch with a second possible correction in midcourse analogous to the Mariner system.

5.3 Terminal Maneuver

Two types of missions around Jupiter have been considered. One type is the fly-by mission following a hyperbolic orbit with respect to Jupiter. A spacecraft approaching to within three Jovian radii would spend approximately 3-1/2 hours on either side of perijove at a distance of four Jovian radii or less. Thus a total of better than seven hours of useful data acquisition time could be obtained with this approach covering most of the Jovian surface providing that the spacecraft passed by the planet in a direction such as to use Jupiter's own rotation to obtain maximum coverage.

The second type of mission would be an elliptical orbit around Jupiter with a perijove of three Jovian radii and an apojove of 100 Jovian radii with a period of 45 days. This assumes that the vehicle approaches Jupiter along an asymptote of seven Jovian radii and that injection thrust is produced at perijove. A curve relating the velocity increment of thrust necessary to enter Jovian orbit as a function of approach velocity is given in Figure 3.

A number of typical mission parameters have been computed involving a variation of boosters, payloads and flight time for fly-by and orbiting missions, and are shown in Table 6. Curves of total spacecraft weight versus excess spacecraft velocity from which these tabular values were obtained are available in the original report if desired.

6. CONCLUSIONS AND FINAL COMMENTS

Scientifically Jupiter is extremely interesting and a number of objectives have been established which are both valuable and suitable for determination from a space probe with a reasonable chance of success. The scientific payload has been based on using largely 'state of the art' instrumentation, some of which has already been flight tested, and should therefore provide reliable data from the planet. However the individual scientific experiments use but a small percentage of the total payload weight and it should be borne in mind that changes can be made relatively easily, if advances in the knowledge of Jupiter or interplanetary space demand this.

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Launch capabilities for Vehicle 1 presently exist for payloads of 350 lbs. or 450 lbs. to fly-by Jupiter using a final solid propellant stage, and a number of launch windows are available in the period between 1969 and 1975. Flight times range from 500 to 800 days for such missions.

Vehicles 2 and 3 provide a greater flexibility in payload, launch windows, and flight time and provide orbiting capability as well as fly-by. Vehicle 3 is capable of performing a Jovian mission without a final solid propellant stage for fly-by, however a 2500 lb. terminal propulsion stage would be required for injection into a Jovian orbit.

In summary, the feasibility study discussed in ASC Report M-1, "Survey of a Jovian Mission" indicates that such a mission is within the reach of the present state of the art, and that a detailed mission study is now needed to establish the design parameters if NASA decides to implement an exploratory mission to this planet.

TABLES AND GRAPHS

Table 1

PHYSICAL AND ORBITAL DATA FOR JUPITER

Physical Data

Mean Diameter	139,800 km
Mean Density	1.33 grm/cc
Mass	318.35 (Earth = 1)
Mean Surface Gravity	2.64 g
Albedo	0.51
Surface Temperature	150°K

Orbital Data

Semi-major Axis	5.2 AU
Perihelion Distance	4.95 AU
Aphelion Distance	5.45 AU
Mean Orbital Velocity	42,800 ft/sec
Period of Revolution	11.86 years
Inclination of Orbit	1.3°
Inclination of Equator to Orbit	3.1°
Period of Rotation	9h 53 ^m
Escape Velocity	197,500 ft/sec

Table 2

SOME SCIENTIFIC OBJECTIVES OF A JUPITER MISSION

- a) To determine the magnetic field of Jupiter
- b) To determine the composition of the Jovian atmosphere, its temperature profile and density
- c) To determine the density and energy distribution of the charged particles in the Jovian trapped radiation belts.
- d) To obtain a photographic record of the planet's cloud cover, and possibly surface features. In particular, to study the red spot.

Table 3

EXPERIMENTS SUGGESTED FOR A FIRST JUPITER
PROBE

- a) A magnetometer to survey both the Jovian and interplanetary magnetic fields.
- b) An infrared spectrophotometer to measure the type and abundance of infrared active molecules that determine the atmospheric energy balance .
- c) A microwave radiometer to probe through the atmosphere and if possible measure the temperature of the surface of the planet.
- d) A visible and ultraviolet spectrophotometer - polarimeter to measure type and abundance of atmospheric constituents, and provide data concerning total pressure, temperature, aurora, and the red spot.
- e) Particle counters to measure flux of cosmic rays, and charged particles either from solar activity or trapped in the planet's magnetic field and micrometeorites.
- f) A TV camera to provide photographs of planetary features.

Table 4

MISSION INFORMATION RATES

	Accuracy	Measurement Rate	Bits per Reading	Bits per Second
Rubidium Vapor Magnetometer (3 axis)	5%	1 per minute	30	1/2
Rotating Coil Magnetometer (3 axis)	1%	6 plus calibration per minute	30	1/2
Infrared Spectrometer	5%	30 minutes for planetary scan	6000	3-1/3
μ Wave Radiometer	1%	30 minutes for planetary scan	28	1/2
U. V. and Visual Spectrometer	5% intensity 1% wavelength	1 planetary scan per hour	10,000	3
200 line T. V.	150 km resolution at 3R	1 planetary scan of 20 frames	2×10^6	See text
Particle Counters	Energy 10%	Integrated particle count 3/sec	4	12
Dust Counters		7/hour	Negligible	
Engineering Data				6
Total				26 b.p.s. plus television (non real-time)

Table 5

POSSIBLE PAYLOAD CONFIGURATION

Payload Type	Exper. Package Weight (lbs.)(1)	Nuc. Power Supply Weight (lbs.)	Attitude Control and Midcourse Guidance (lbs.)	Shield Weight (lbs.)	Ancillary Structure & Equipment (lbs.)	Total Weight (lbs.)	
A	45	200	90	30	95	460	
A*	see note below						350
B	200	1000	175	150	420	1945	
C	200	3500	1300	2500		9500	

(1) Experimental packages A and A* cover magnetometer, IR equipment and particle counter only. Packages B and C cover all experiments including TV.

A* Payload assumes that optimization will be achieved for the data transmission rate, power supply rating, and battery storage coupled to the isotopic power unit. An increased power efficiency of the transmitter or the use of laser communications could lead to a significant weight reduction.

Table 6
COMPARISON OF MISSIONS TO JUPITER

Launch Vehicle	Mission Type	Payload (lbs.)	Ideal Velocity (ft/sec)	Flight Time (days)	Launch Years	Launch Window (days)	Remarks
Vehicle 1 plus solid propellant stage	Flyby	A* -350	53, 200	800	1969-75	20	
	Flyby	A* -350	53, 200	600	1969-75	25	
	Flyby	A* -350	53, 200	500	1972	10	
	Flyby	A-450	52, 000	800	1969-72	20	
	Flyby	A-450	52, 000	600	1971-72	15	
Vehicle 2 plus LH ₂ /Lox stage (30, 000 lbs.) plus solid propellant stage	Flyby	A* -350	59, 000	400	1973 and 74	20	
	Flyby	A-450	58, 000	400	1973 and 74	15	
	Flyby	B-2000	51, 000	1000	1969	25	
	Flyby	B-2000	51, 000	800	1969	10	
	Flyby	B-2000	51, 000	800	1971	15	
Vehicle 3	Flyby	B-2000	58, 500	400	1973 and 74	20	
	Flyby	B-2000	58, 500	500	Annual	30	Excess capability available for most opportunities.
	Orbiter	B-2000	56, 500	600	Annual	30	Allowance has been made for 2500 lbs. terminal propulsion.
Vehicle 3 plus LH ₂ /Lox stage (30, 000 lbs.)	Flyby	B-2000	63, 500	Approx. 350	1974	10	
	Orbiter	B-2000	57, 000	500	Annual	30	Allowance has been made for 7350 lbs. terminal propulsion.
	Orbiter	C-10, 000	52, 000	800	1969 and 71	20	Allowance has been made for 11, 600 lbs. terminal propulsion

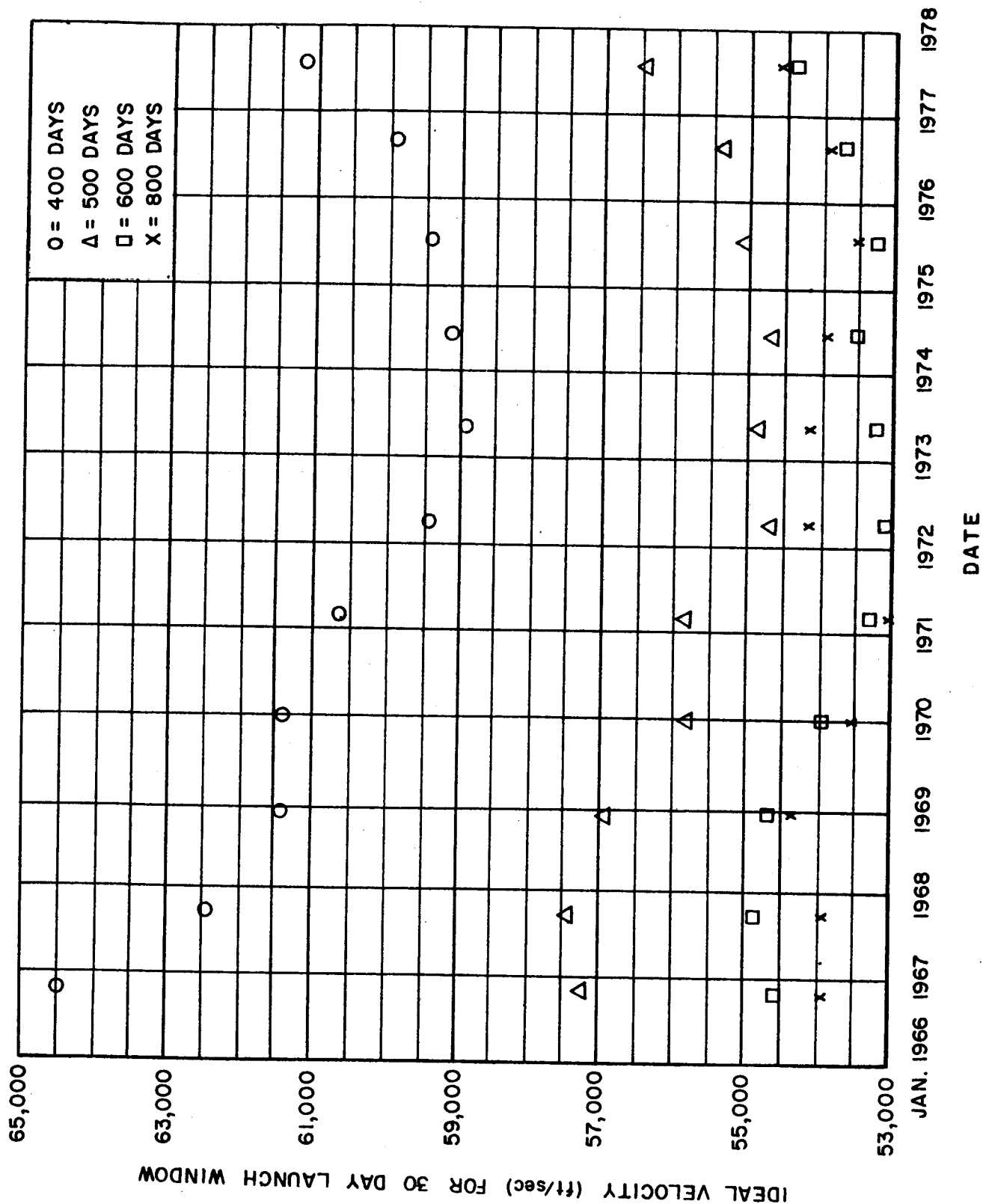


FIG 1 LAUNCH OPPORTUNITIES FOR JUPITER

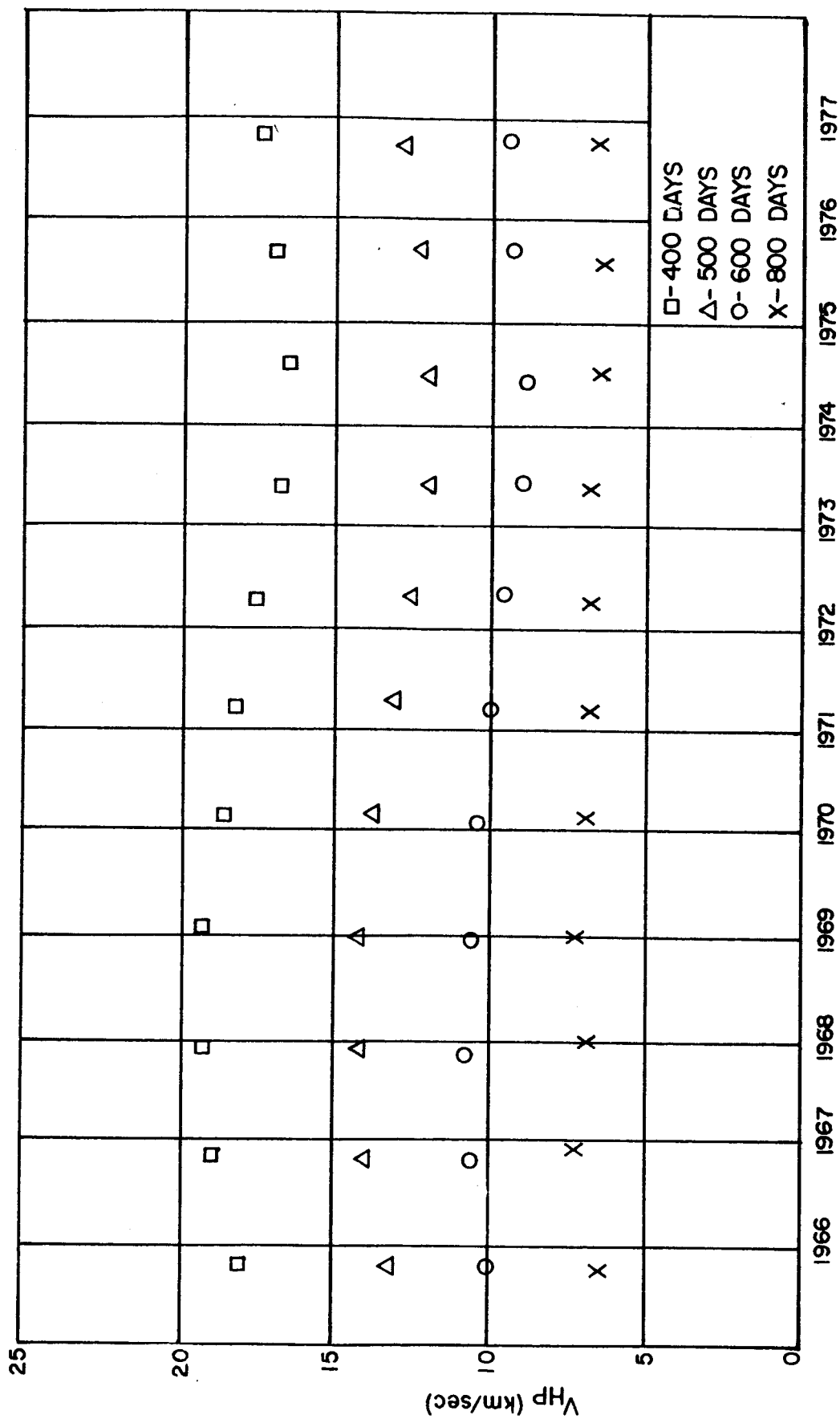


FIG.2
HYPERBOLIC EXCESS SPEED AT JUPITER, V_{HP} , AS A
FUNCTION OF LAUNCH DATE AND FLIGHT TIME

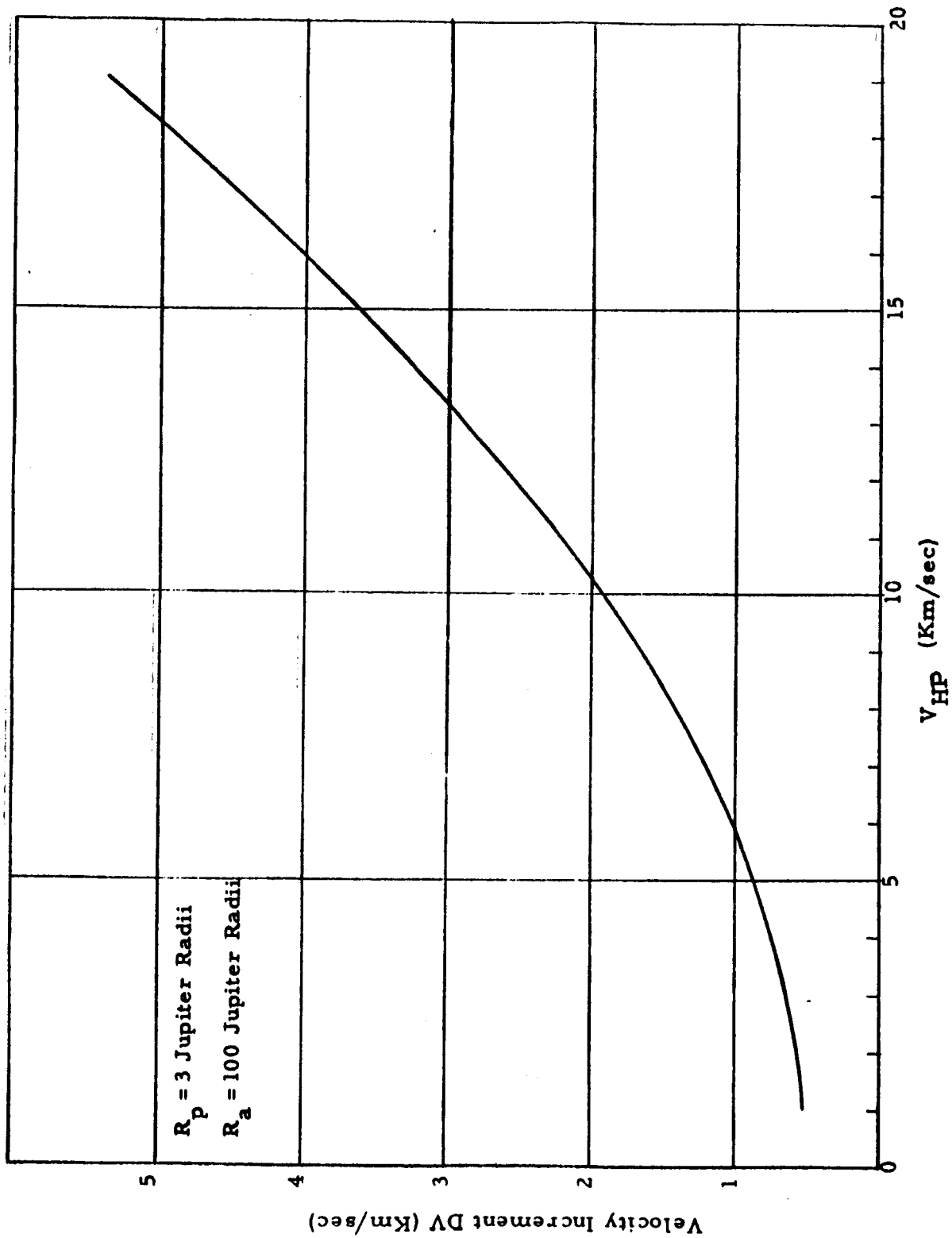


Fig. 3 VELOCITY INCREMENT TO ENTER JOVIAN ORBIT AS A FUNCTION OF V_{HP}

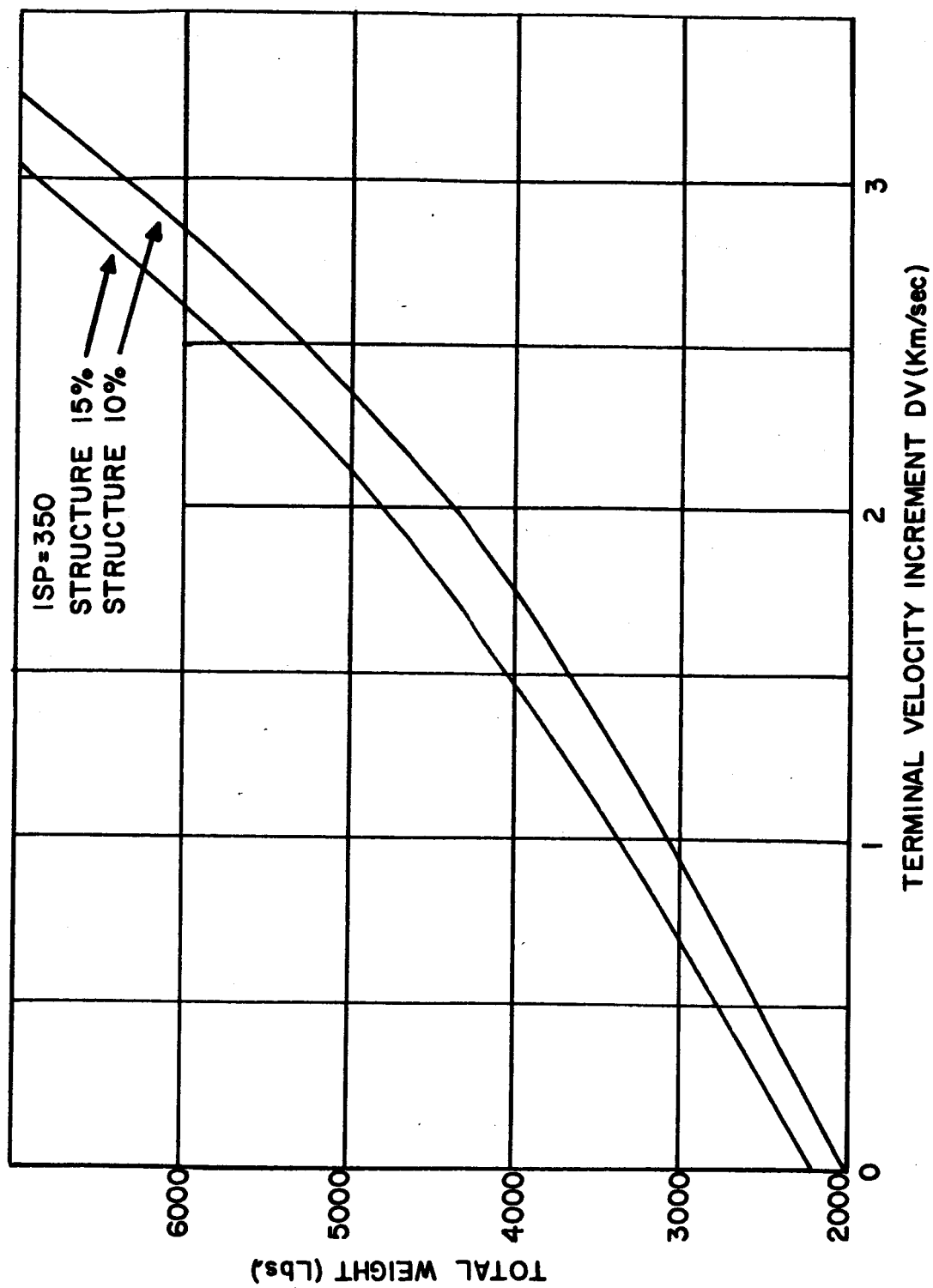


FIG. 4 SPACECRAFT WEIGHT REQUIRED TO PLACE 2000 Lbs. IN ORBIT
AROUND JUPITER AS A FUNCTION OF TERMINAL VELOCITY INCREMENT